٢١٠ Part (2) بصريات ١/٢ / Optics / إلكترونيات ٤

Sec (2) **Energy Bands In Solid**

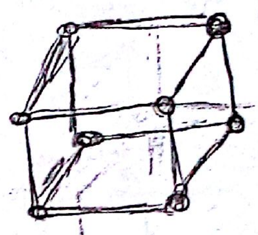
1 Formation of Energy band in SemiConductors

Most of SemiConductors has crystalin form
e.g. Cubic crystal → Simple Cubic
↳ Body centered Cubic
↳ Face Centered Cubic

A Simple Cubic lattice

↳ There are 8 atoms in Corners

↳ each atom is Shared with 8 unit cells

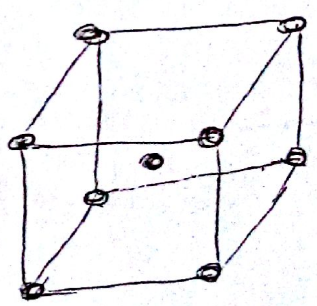


Watch a Video in youtube if you don't under Stand the shape

∴ No. of atoms per unit Cell $= 8 \cdot \frac{1}{8} = 1$ atom

B Body Centered Cubic Lattice →

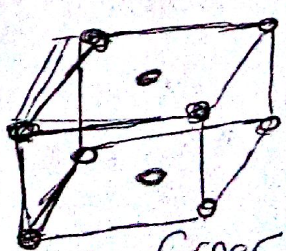
↳ 8 Atoms in Corners
+ one atom incide unit cell



↳ No. of atoms per unit cell
$= (8 \cdot \frac{1}{8}) + 1 = 2$ atoms

C Face Centered Cubic lattice

↳ Cubic has 6 faces
↳ each face Contain atom
↳ each atom is Shared between 2 ~~...~~ unit Cell + 8 Atoms in Corner



↳ No. of atoms per unit cell $= (6 \cdot \frac{1}{2}) + (8 \cdot \frac{1}{8})$
$= 3 + 1 = 4$ atoms

Valence Electrons الكترونات التكافؤ

Ex. of Semiconductors : "Most used semiconductor in optoelectronics"

Just to Remember Semiconductors

1 Silicon (Si)

$Si_{14} \rightarrow 1s^2, 2s^2, 2p^6, 3s^2, 3p^2$

المستوى الثالث هو المستوى الاخير و فيه ④ الكترونات
نسميها Valence electrons

$Si \xrightarrow{has}$ 4 valence electron /atom

2 Ge^{32}

$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^{10}, 4s^2, 4p^2$

$Ge \xrightarrow{has}$ 4 valence electron /atom

3 Ga^{31}

$1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^{10}, 4s^2, 4p^1$

3 valence electrons /atom

4 As^{33}

↳ $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 3d^{10}, 4s^2, 4p^3$

↳ has 5 valence electrons /atom

Q (7) Calculate an avg number for the Valence electrons per unit Volume in Semi Conductor crystals?

~Sol~ 1) Calculate Volume of unit cell

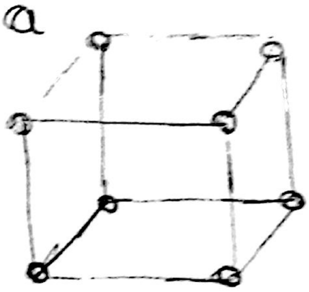
2) Calculate atoms / unit cell

3) Estimate no. of electrons / unit Volume

→ For simplicity Let's take Simple Cubic lattice.

Semi Conductor crystal
→ SC → ✓
→ BCC
→ FCC

Interatomic Space $= a$



1) ∴ Volume of Simple Cubic $= a^3$

In SemiConductors $a = 3-7\ A^\circ$ ⟷ a

assume $a = 5\ A^\circ$

∴ Volume of unit cell $= (5)^3 = 125\ A^{\circ 3} = 125 * 10^{-24}\ cm^3$

$1A^\circ \rightarrow 10^{-10}\ m$

$1A^\circ \rightarrow 10^{-8}\ cm$

2) Atoms / unit cell

$= 8 \cdot \frac{1}{8} = 1$ atom

3) No. of atoms / unit Volume $= \frac{1}{125 * 10^{-24}} = 0.8 * 10^{+22}\ cm^{-3}$

4) Valence electrons / atom $\simeq 4$ electrons / atom

5) ~~Electron~~ Avg. no. of Valence electrons / unit Volume

$= 0.8 * 10^{+22} * 4 = 3.2 * 10^{+22}$ electron / cm^3

Note
+ve → Sign
Very Large no. → $\simeq 10^{+22} \rightarrow 10^{+23}$ electrons / cm^3

Energy Bands in Solids

1] Solid is state of $\boxed{\text{matter}}$

→ Collection of atoms

+ve nuclear ← / −ve charged electrons

To study Behaviour of electrons ← −ve charged electrons

⇓

Schrodinger eqn.

Schrodinger eqn.

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{2m}{\hbar^2}(E-U)\psi = 0$$

E → Total energy → this is eign value of this eqn.

$$\frac{\partial^2 \psi}{\partial x^2} = -\frac{2m}{\hbar^2}(E-U)\psi$$

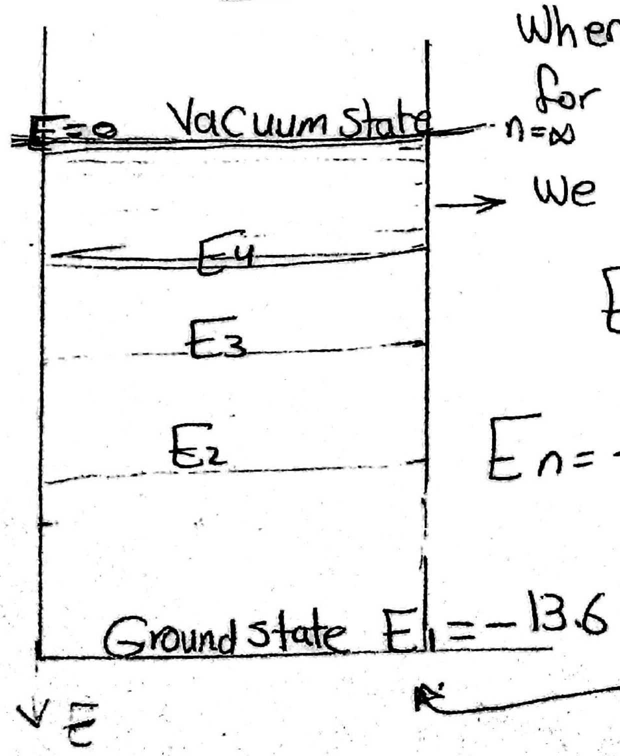
ψ → هي داله لو اخذت لها المشتقة التانيه هتفضل كما هي لكن مضروبة في قيمة القيمة دي بنسميها eign value

- IF we take isolated atom ~ Simple atom has one electron

$\boxed{\text{e.g}}$ Hydrogen atom

When we solve schrodinger eqn. for this atom.

→ we found that E is quantized "discrete" تعتمد على ⓝ



$$E_n = \frac{-me^4}{8\epsilon_0^2 h^2}\cdot\frac{1}{n^2}$$

$n = 1, 2, 3, \ldots$

$$E_n = -\frac{13.6}{n^2}\ \text{eV}$$

→ discrete قيم منفصلة

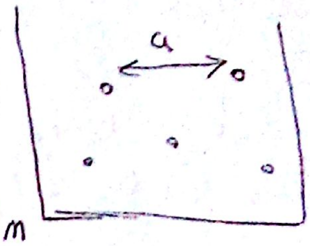
∴ Isolated Atom Can be characterized by discrete Energy level.

→ Note In gas

Space = a

↳ interatomic ~~between~~

= 100 A° → 1 μm

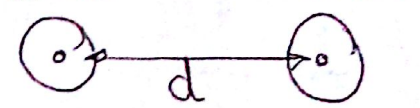


But

↳ In Semiconductors $a = 5\ A°$

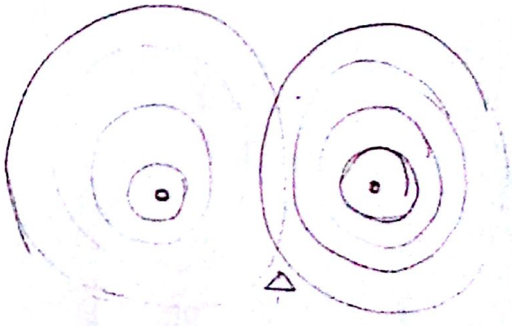
↳ When (d) is large

we Can Consider each atom is isolated atom → ∴ energy band will be discrete



↳ When d is Small

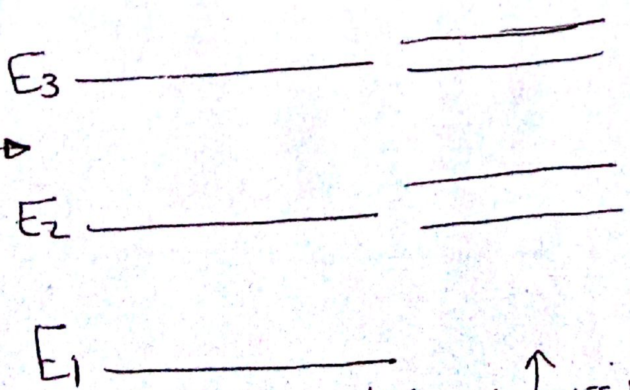
عندما ~~[illegible]~~ تقترب ~~[illegible]~~ ذرتين من بعضها فإنه يحدث Split "انفصال" لـحالة الطاقة Energy state إلى 2-Energy state



Outer energy level will split

← لو ~~[illegible]~~ تقارب عدد كبير من الذرات يحدث splitting لـ energy state مكون energy Band

الذى يتأثر بالـ splitting هى الـ energy state الخارجية وليست ~~[illegible]~~ القريبة من النواه



Ground State الـ

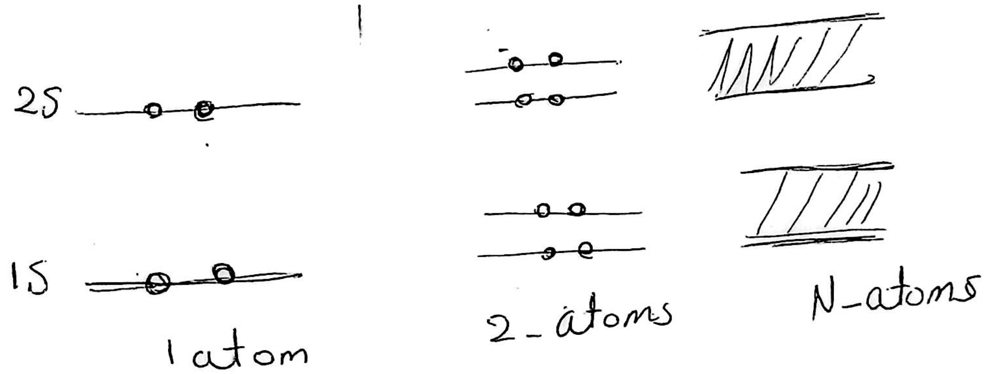
هذا هو الحال لو تقارب ذرتين فقط

For Reading

Pauli Exclusion principle

مبدأ بولي للاستبعاد

If two or more atoms are brought together, thier outer (i.e Valence) energy Level must be split so the will be differant from one another

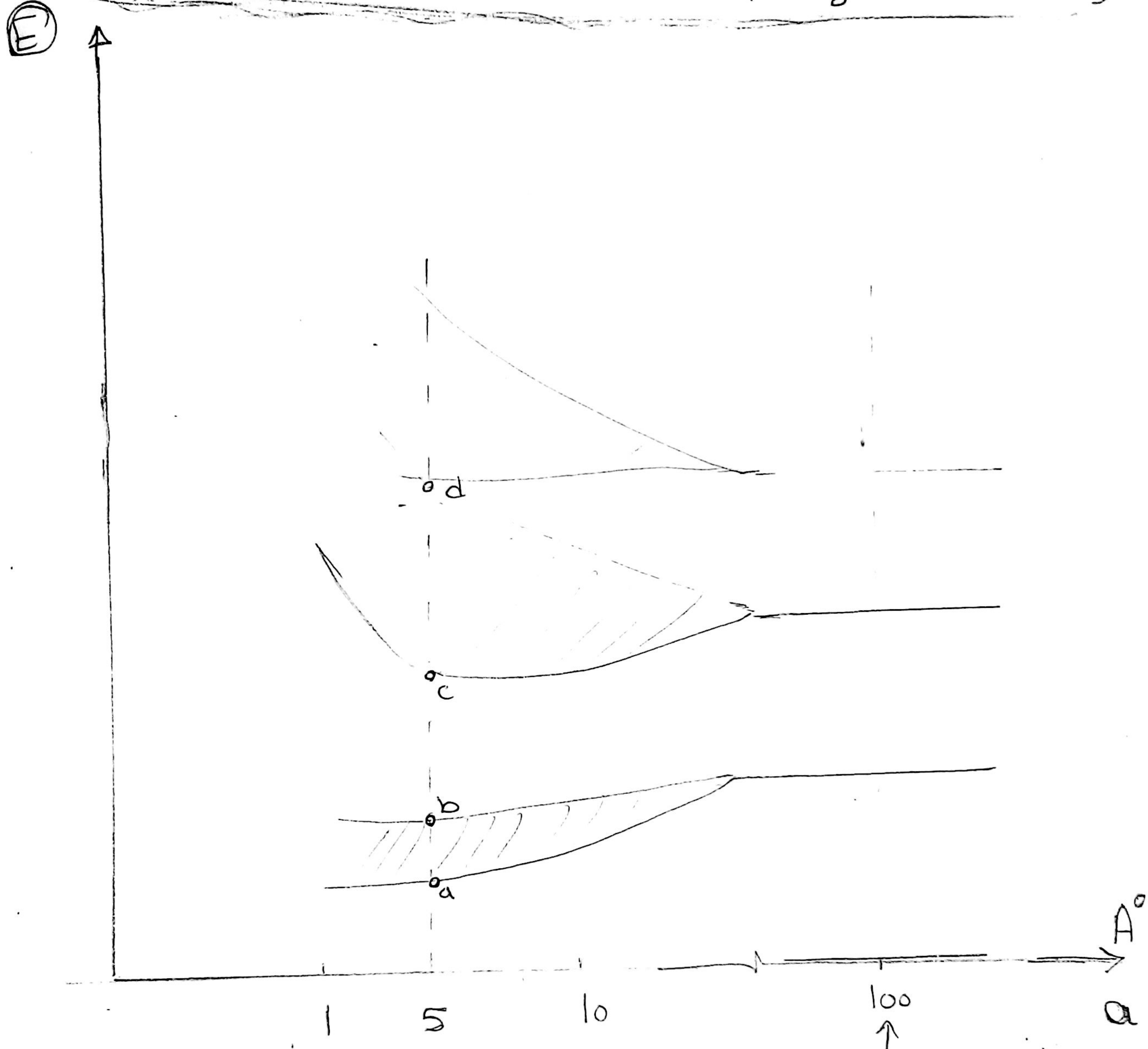


في فيزياء ثانويه عامه بنفس المبدأ

مبدأ بولي:
في ذره ما لا يوجد
الكترونات لهما نفس
اعداد الكم الاربعه

لذلك لما كنت بقول
$3S^2$
في الكترونين في 3S
3S ↑↓
بيقول ان فيه الكترون
بيدور مع عقارب الساعه
و اخر عكسها

Q8 Draw a relation between Atom energy and the interatomic spacing between atoms)



interatomic space

→ Semi Conductor

→ 10^{22} atom / cm^3

→ $a \simeq 5\ A°$

→ d → Energy level is → Energy Band

not discrete

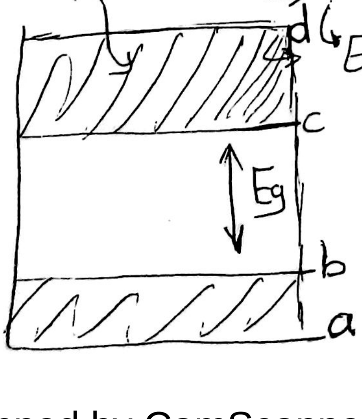
Like in gas

isolated atoms

" $E \rightarrow$ discrete "

Band Diagram

Conduction Band



← Valence Band

|Q(2)|

$\boxed{\text{Sec }(2)}$

↳ $E = E_K + E_p$

$$E = \frac{1}{2} m v^2 + \left(\frac{-e^2}{4\pi \varepsilon_0 r} \right) \rightarrow \text{(I)}$$

for reading only

↳ our target → to get V → as function of (n)

r → as function of (n)

↳ Solution of Schrodinger eqn. :

$$\psi(x) = e^{jkx}$$

L

↳ this function is periodic every (L)

$$\psi(x) = \psi(x+L)$$

$$e^{jkx} = e^{jkx} \cdot e^{jkL}$$

$$\therefore kL = n(2\pi) \qquad n = 1, 2, 3, \ldots$$

$$k = \frac{2\pi n}{L} \longrightarrow k \text{ is quantized}$$

محيط الدائرة

$$\because L = 2\pi r \Rightarrow \boxed{k = \frac{n}{r}}$$

$$\therefore \boxed{r = \frac{n}{k}} \rightarrow (1)$$

↳ De-Broglie Relation

$$P = \frac{h}{\lambda}$$

$$= \frac{h}{2\pi} \cdot \frac{2\pi}{\lambda}$$

$$\rightarrow P = \hbar k = \hbar \frac{n}{r}$$

$$P \cdot r = \hbar \cdot n$$

$$m V r = \hbar n$$

$$\therefore \boxed{V = \frac{\hbar n}{m r}} \rightarrow 2$$

↳ Coulomb's Force

$$f_c = \frac{e^2}{4\pi\varepsilon_0 r^2} \rightarrow 3$$

$$\& \; f = m.a = m . \frac{v^2}{r} \rightarrow 4$$

From 3 & 4

$$\therefore \frac{e^2}{4\pi\varepsilon_0 r^{\cancel{2}}} = m . \frac{V^2}{\cancel{r}}$$

$$V^2 = \frac{e^2}{4\pi\varepsilon_0 \, r . m} = \frac{e^2}{4\pi\varepsilon_0 m . r} \rightarrow 5$$

~~square of~~ Eqn 2 power 2

$$\therefore V^2 = \frac{\hbar^2 n^2}{m^2 r^2}$$

$$\therefore \frac{e^2}{4\pi\varepsilon_0 \cancel{m}\cancel{r}} = \frac{\hbar^2 n^2}{m^{\cancel{2}} r^{\cancel{2}}} \qquad \hbar^2$$

$$\therefore r = \frac{\hbar^2 n^2 . 4\pi\varepsilon_0}{m e^2} = \left(\frac{h^2}{4\pi^2}\right)\frac{n^2 . 4.\pi\varepsilon_0}{m e^2}$$

$$\therefore \boxed{r = \frac{h^2 n^2 \varepsilon_0}{\pi m e^2}} \rightarrow 6$$

⤳ r as function of n

From 6 → into 2

$$\therefore \boxed{V = \frac{h}{2\cancel{\pi}} \cdot \frac{\cancel{n}}{\cancel{m}} \cdot \frac{\cancel{\pi} \cancel{m} e^2}{h^{\cancel{2}} n^{\cancel{2}} \varepsilon_0} = \frac{e^2}{2 h n \varepsilon_0}}$$

↳ 7

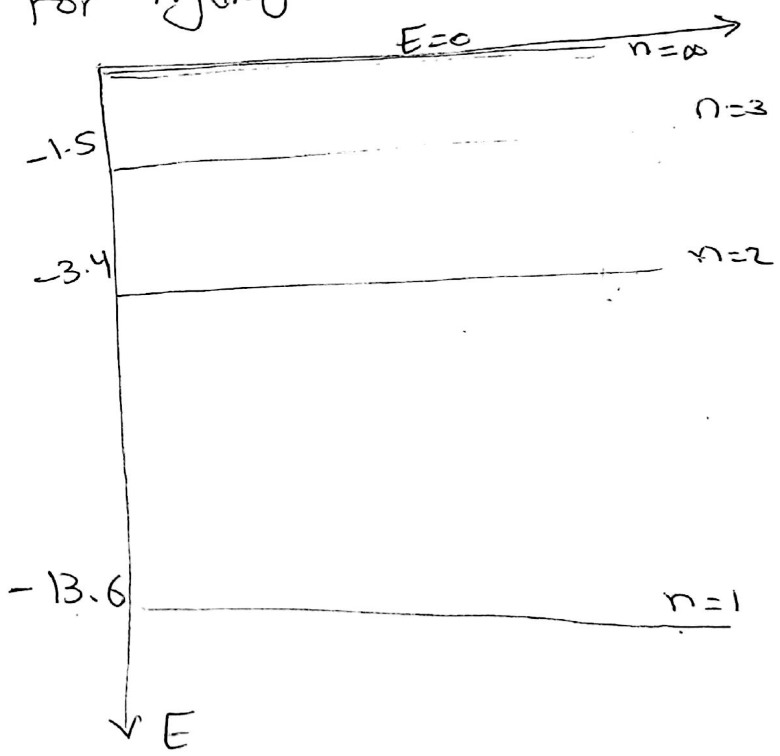
$$\therefore\ E_K = \frac{1}{2} m v^2 = \frac{e^4 m}{8 h^2 n^2 \varepsilon_0^2} \longrightarrow \text{II}$$

$$E_p = \frac{-e^2}{4 \varepsilon_0^2 h^2 n^2} \longrightarrow \text{III}$$

From II & III into I

$$\therefore\ E = \frac{-e^4 m}{8 h^2 n^2 \varepsilon_0^2} = \frac{-13.6\ \text{eV}}{n^2}$$

For hydrogen



(c) $E_{photon} = E_2 - E_1 = -3.4 - (-13.6) = 10.2\ \text{eV}$